RESEARCH DEPARTMENT

THE RANGE OF COLOURS EXCITED BY A TWO-COLOUR REPRODUCTION SYSTEM

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SUMMARY

Some experiments are described in which two-colour and three-colour reproductions of the same scene are compared. Optical projection of the separation positives was used in the main but a description of a colour television demonstration is also given. The accuracy of a two-colour process is assessed on the basis of the colour names given to specified areas of the colour reproductions in the two-colour and three-colour versions.

1. INTRODUCTION

In the early days of colour cinematography a number of two-colour processes[1] were operated with a fair measure of success.

One such process was the Raycol additive two-colour process, which operated during 1928-29. Red and green separation positives were projected and combined in register on the screen. Originally the green separation was projected through a blue-green filter but it was found that the filter was unnecessary. The red positive was projected through a red filter. The effect is described by Clyne[1] as being "astonishingly good". Baird experimented with a two-colour television system and gave a demonstration of a 600-line picture in 1941 using a two-colour frame sequential system.[2] More recently interest in this subject has been stimulated by Land,[3] who has claimed that the "full gamut of color" can be produced by a two-colour process.

One form of two-colour process described by Land closely resembles the Raycol process described above. The green and red separations are used; the green is projected in a black-and-white projector and the red separation is projected through a tricolour red filter. Land has not claimed that the colours are accurately reproduced, but he states that pleasantly coloured scenes are generated by these means. The experiments about to be described probably support the latter claim, but the primary purpose was to obtain statistical data on the subjective accuracy of colour reproduction of this two-colour process.

2. EXPERIMENTAL PROCEDURE

Three-colour separation positives of a number of scenes were prepared; some were obtained by direct photography through tricolour red, green and blue filters. Others were obtained from Ektachrome transparencies using the recommended

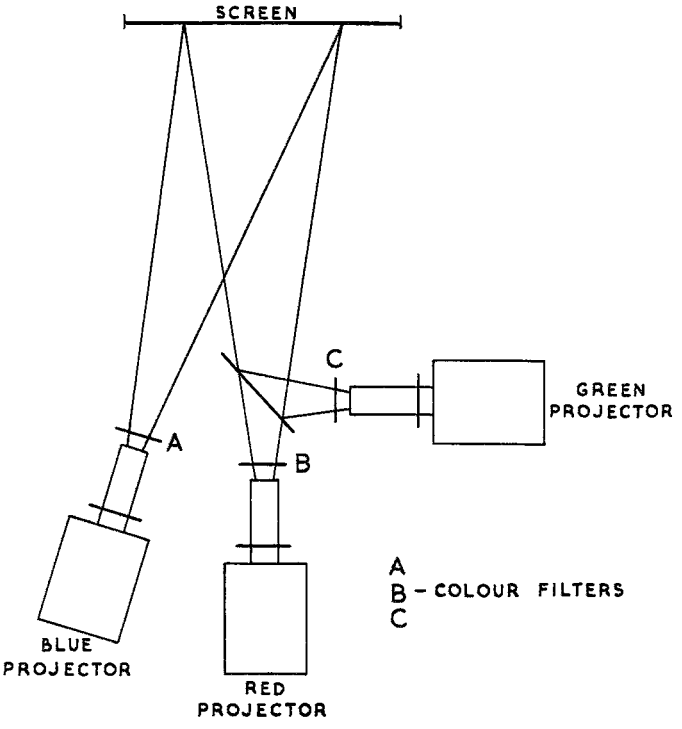


Fig. 1 - Schematic of triple projector

techniques. A triple projector (Fig. 1) was improvised by using three Aldis projectors. This arrangement, using a titanium dioxide mirror, permitted exact registration to be obtained as between the red and green images. The blue image suffered slight keystone distortion as compared with the other images, but this did not appear to cause any appreciable trouble, presumably because of the relatively low luminosity of the blue component. The colour picture was projected on to a matt white screen. The size of image was about 15 in. × 20 in. (38 × 50 cm) and the image was viewed at a distance of about 7 ft (2·1 m). Thus the ratio of viewing distance to picture height was 5·6, which is typical of critical viewing of television pictures although it is a smaller ratio than that generally applying to the viewing of a 21 in. (53 cm) television picture (405-line) in the home. The peak-white brightness was of the order of 3 to 5 ft-lamberts (30 to 50 asb) which is rather less than that available from a colour television tube (e.g. R.C.A. type 21AXP22).

For a three-colour presentation, all three projectors were used: the projectors giving the blue and red images were fed from continuously variable voltage transformers. This feature enabled the colour balance to be varied over wide limits. The values of voltage were chosen to give a satisfactory appearance of the colour scene.

For a two-colour presentation, the blue projector was switched off and the green filter was removed from the "green" projector and replaced by a colour-temperature-raising filter.* The filter in the red projector was unaltered and the voltage

*This was estimated to raise the colour temperature of the projector light from 3000° K to about 4500° K. This is nearer to the chromaticity of a monochrome television tube and was found to improve the saturation of the colours given by the two-colour process.

on this projector was adjusted to give the best results. This implied, in practice, the adjustment for which the maximum range of colours was produced without making the whites in the two-colour reproduction obviously pink. An increase in the light flux from the red projector beyond the condition just described gave more saturated colours but the whole colour balance clearly suffered from an excess of the red component.

From this description of the synthesis of a two-colour picture, it will be observed that the image is built up by the addition of white and red light in various proportions. Hence, one might even regard this synthesis as "white plus one colour", reserving the description of "two-colour" for combinations of complementary colours such as red and cyan. The white-plus-red system will, however, be described as "two-colour".

If one ignored effects such as simultaneous contrast, it might be thought that the two-colour presentation just described would produce a very restricted range of colours which would include only reds, pinks, whites and greys. Because of simultaneous contrast effects, however, a much greater range of colours is produced and blue-greens are clearly in evidence. The mechanism by which this takes place may be as follows: the highest luminances in the scene are usually accepted as white by the observer, provided that they are not markedly coloured as compared with other objects in the scene. This means that the subjective white point moves to a position on the colour triangle somewhere between the chromaticity of illuminant B and that of tricolour red, e.g. the point X in Fig. 2. Thus from X to R we have physical stimuli which give rise to sensations of red of various intensities, whilst from X to B the sensation of the colour complementary to red, namely blue-green, is produced.*

Further discussion of the colours produced by a two-colour system will be deferred until the experimental results have been given.

3. RESULTS

Four scenes were used as subjects for experiment. In three of these the colour separation positives were obtained by direct photography. The other picture was originally photographed on Ektachrome sheet film and the colour separations were obtained from the colour transparency.

The observers were shown a colour picture (either two- or three-colour) and asked to name the colours in certain specific areas. No restrictions were placed on the colour namings, although it was explained that consistency of naming was desirable. Having listed the colours seen in (say) the two-colour reproduction, the observer was then asked to give colour names to the same areas of picture in the three-colour reproduction. For the first three pictures six male observers were used; for the fourth picture six female and six male observers were used. Only one observer was questioned at any one time, so that the colour namings are individual opinions and not the result of a group discussion.

*Since the completion of this report, a confirmation and extension of this idea has been published by Karp, "Colour-Image Synthesis with Two Unorthodox Primaries", Nature, Vol. 184, pp. 710-712, 29th August 1959.

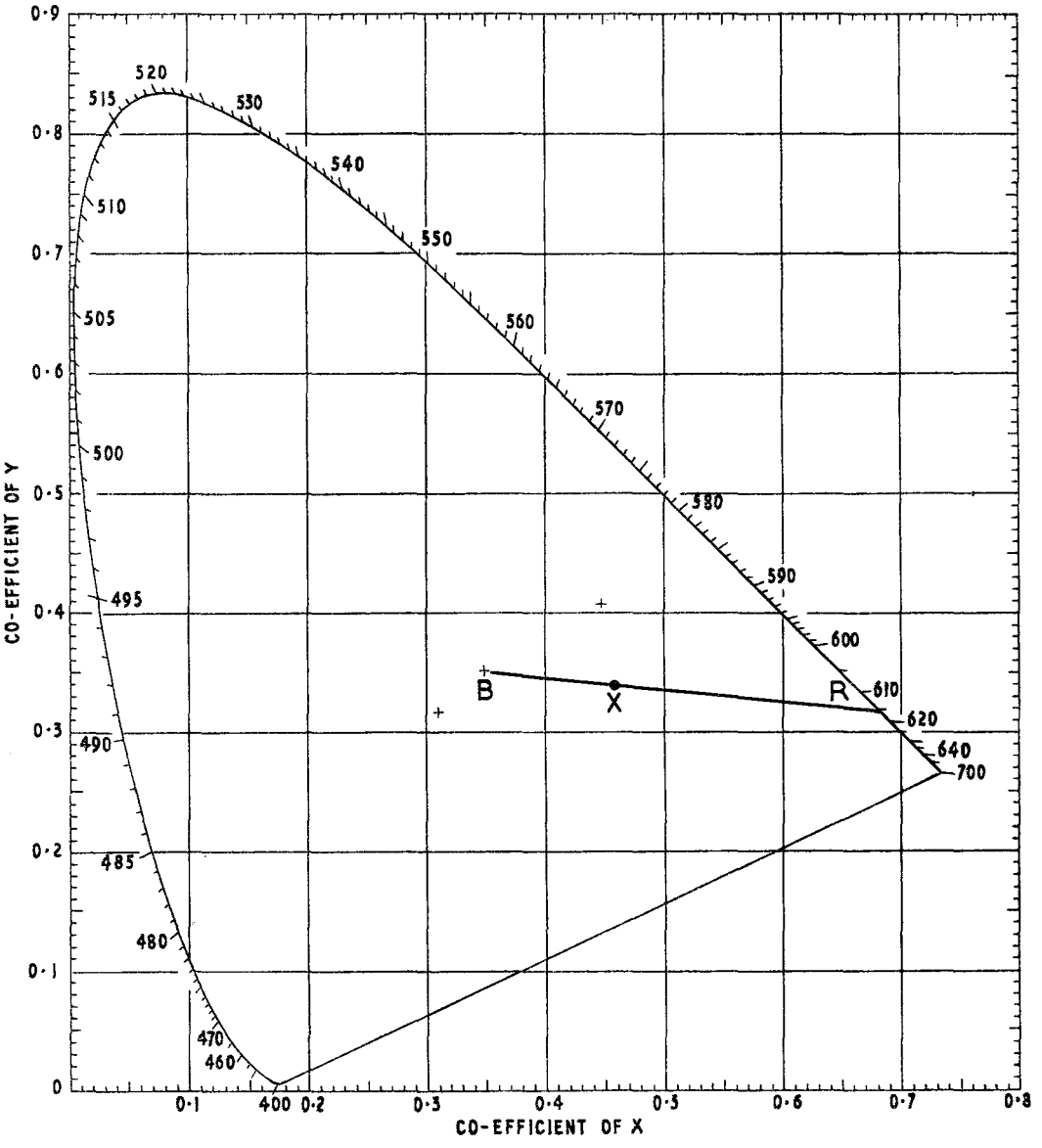


Fig. 2 - Range of chromaticities objectively produced by two-colour process

3.1. Colour Patches

This "picture" consists of thirteen colour patches of rectangular shape. Figs. 3(a) and 3(b) show black-and-white prints of the red and green separation positives, respectively. Table 1 gives the percentage of observers who gave

(a) identical namings
(b) identical and similar* namings

} to the two-colour and three-colour versions

In all cases the two-colour version was shown first and then the three-colour version.

*The definition of the "similar" class of namings is somewhat flexible and is not capable of being precisely defined, but the general principle followed was to allow slight changes of hue or saturation as being in the "similar" classification. A marked change in either quality was sufficient to make the namings "different". The only category about which there can be no argument is the "identical" one. See Appendix for the detailed results for the first picture.

TABLE 1

Colour patch number	Colour of original	Approximate chromaticity co-ordinates of original illuminated by source C		Identical namings %	Identical and similar namings %
		x	y		
1	Red	0·43	0·29	50	50
2	Cyan	0·23	0·25	17	50
3	Brown	0·47	0·28	50	83
4	Orange-yellow	0·47	0·44	0	17
5	Green	0·28	0·45	0	17
6	Green	0·28	0·45	0	17
7	Red	0·43	0·29	50	67
8	Blue	0·21	0·17	0	0
9	Orange-yellow	0·47	0·44	17	17
10	Brown	0·47	0·28	67	100
11	Violet	0·23	0·15	0	0
12	Brown	0·47	0·28	50	100
13	Light green	0·36	0·49	0	0

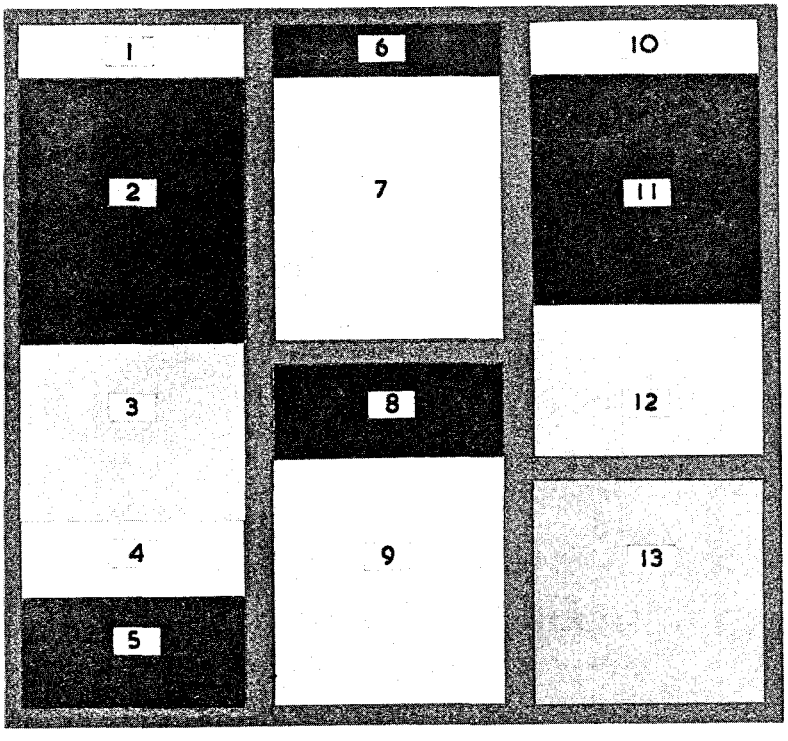
From Table 1 it is fairly obvious that certain colours are not well reproduced, at least under the circumstances that apply in Figs. 3(a) and 3(b), and these are orange-yellow, blue, violet and light green. Colour patch No. 2 (cyan) is moderately well reproduced with 50% of the observers in the "identical and similar" class of namings.

3.2. Teapot Slide

The colour separation positives were prepared from an Ektachrome transparency. This picture, Figs. 4(a) and 4(b), was used considerably during the field trials of colour television[4] and is an attractive composition (in contradistinction to the previous "picture"). The observers were asked to name sixteen coloured patches; some of these colours subtended large* solid angles at the observers' eyes but others did not. The results (Table 2) show that whereas a large-area yellow (such as the Kodak box) is not well reproduced in the two-colour version, nevertheless the second and fifth letters of "POLLY", which are also yellow, are tolerably well reproduced. This suggests that the range of colours which can be simulated by a two-colour process is not precisely defined, but is influenced by size and also by the presence of other colours in the immediate vicinity. Likewise small-area blue (colour patch No. 5 (iv) in Table 2) is seen by four of the six observers, although the large-area blue in the first picture (Table 1, colour patch No. 8) was not recognizably reproduced at all.

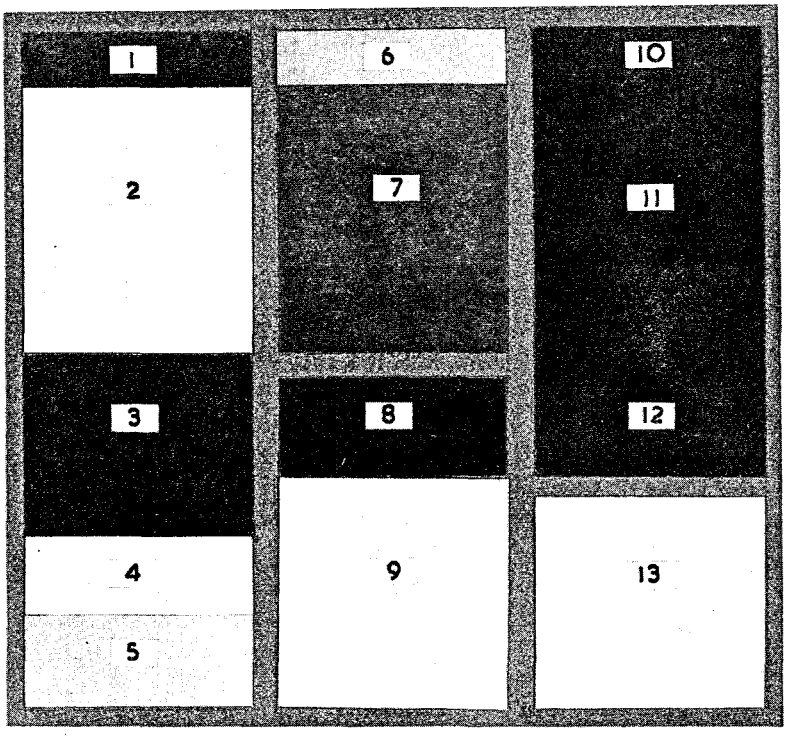
In a picture such as the teapot slide one is surprised by the range of colours which are reproduced by a two-colour process. Nevertheless, it is difficult

*Large compared with the limit of visual acuity (1 minute of arc).



(a) Red separation positive

Fig. 3
Colour patches



(b) Green separation positive

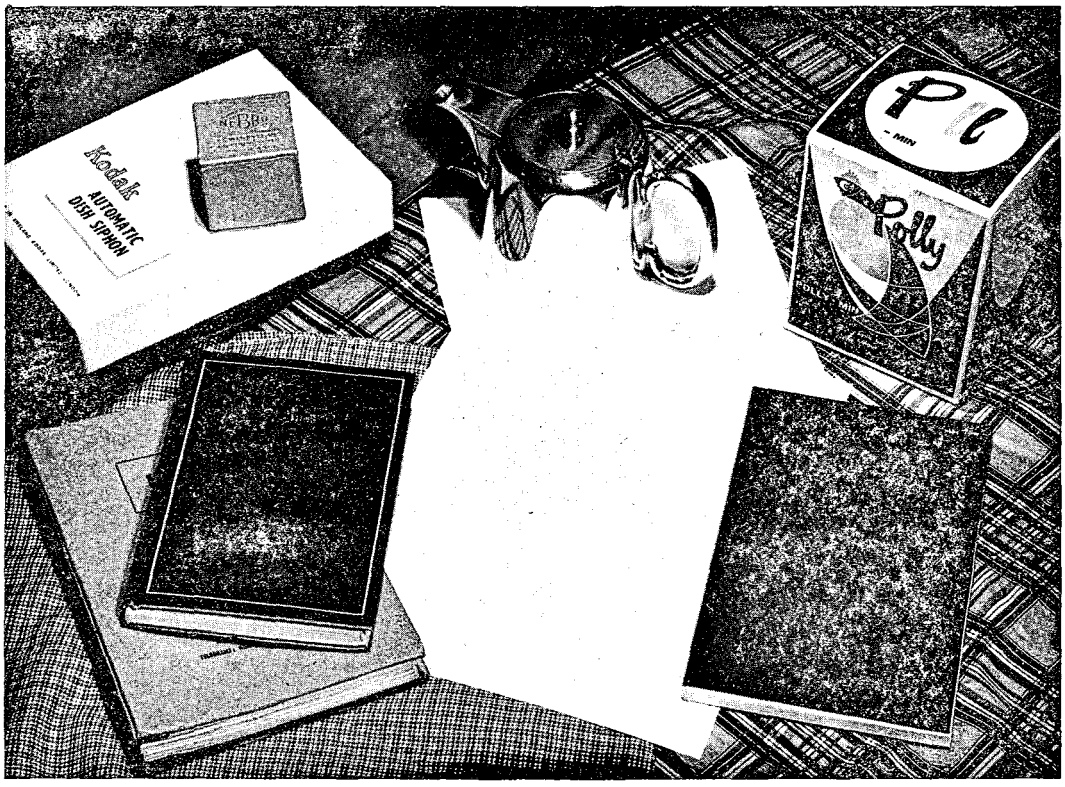


Fig. 4 (a) Teapot slide: red separation positive

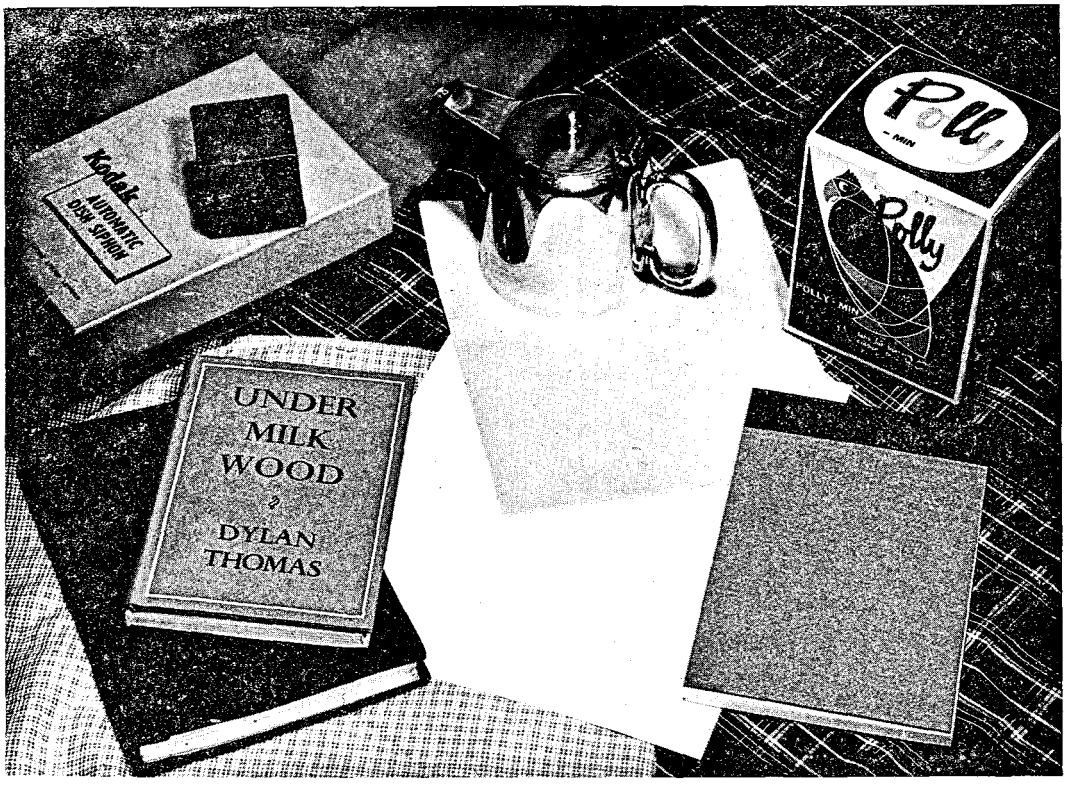


Fig. 4 (b) Teapot slide: green separation positive

TABLE 2

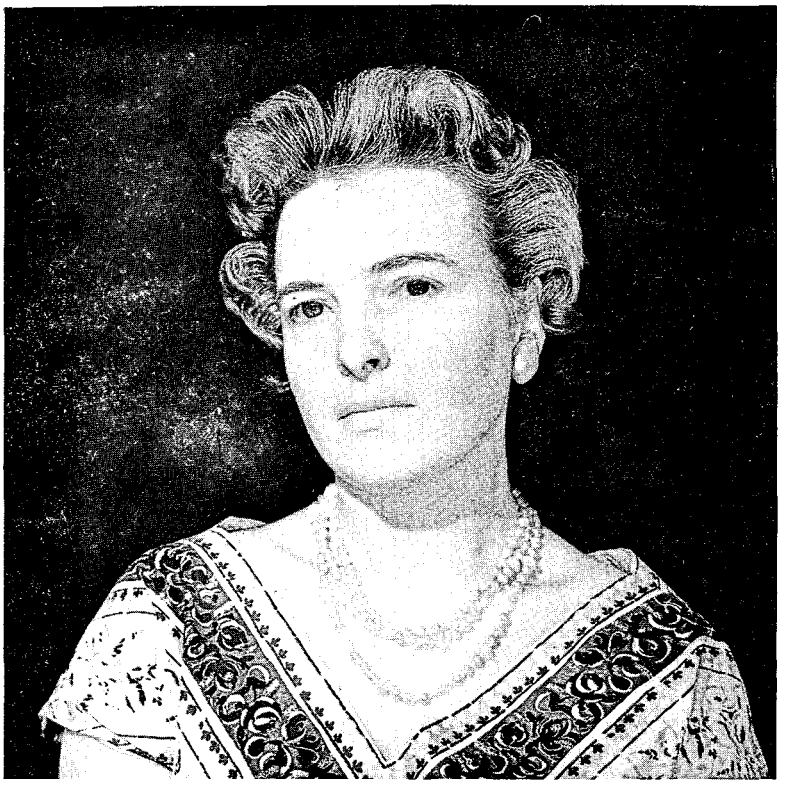
Colour patch number	Subject	Approximate colour of original	Identical namings %	Identical and similar namings %
1	Kodak data book	Red	50	83
2	"Under Milk Wood"	Cyan	0	33
3	Kodak syphon box	Yellow	0	0
4	Slide box	Red	50	83
5 (i)	P (Letters on lid of "POLLY" box)	Green	33	83
(ii)	O	Yellow	83	83
(iii)	L	Red	83	100
(iv)	L	Blue	67	67
(v)	Y	Yellow	67	67
6	B.B.C. notebook	Blue	0	67
7 (i)	Duster	Light green	33	33
(ii)		Green	17	17
8 (i)	Tartan	Red	50	83
(ii)		White	80	80
(iii)		Dark green	67	83
9	Notepaper on which teapot is standing	Pink	67	100

to regard the reproduction as satisfactory when a large bright yellow box is reproduced as pink.

3.3. Portrait

The separation negatives for this picture were taken directly by successive exposures through tricolour red, green and blue filters. This required the model to be still for 55 seconds, but the registration of the positives was nevertheless good, Figs. 5(a) and 5(b). Twelve colours were named by the observers; the results are given in Table 3.

On the whole, the two-colour version of this slide succeeds fairly well; the most obvious deficiency is the green of the dress material (colour patch No. 7 (a), Table 3). One point of interest is that many of the observers thought that the two-colour version was preferable because of an imperfection in colour rendering in the three-colour version, which caused certain highlights on the forehead to be reproduced with a greenish tinge. Since this was clearly an artifact it would not be fair to



(a) Red separation positive

Fig. 5
Portrait

(b) Green separation positive

TABLE 3

Colour patch number	Subject	Approximate colour of original	Identical namings %	Identical and similar namings %
1	Flesh tones on face	Pink	50	100
2	Lips	Red	17	100
3	Eye colour	Grey-green	67	83
4 (a)	Beads	Red-brown	17	33
(b)		Pink	50	83
5	Earring	Red	33	67
6 (a)	Hair	Brown	50	100
(b)		Auburn	20	40
7 (a)	Dress material	Green	0	33
(b)		Black	100	100
(c)		White	50	83
(d)		Red	50	83

infer that, in general, a two-colour version would be preferred. It should, however, be borne in mind that the balance of a three-colour print can be disturbed easily, and that a trend towards either green or magenta in flesh tones is highly undesirable.

3.4. Detergents

Six packets of detergent were photographed and direct separations made. Figs. 6(a) and 6(b) show the red and green separation positives. These packets are brightly coloured, and the colours are sufficiently well known for the observers to be asked about the accuracy of colour in the two-colour and three-colour versions in addition to the colour namings. Sixteen colours were named by the observers, who for this picture included six women in addition to the six men. Three of the women were shown the three-colour version first, and then the two-colour version, and the other three women saw the two-colour version first. This procedure was also followed for the six male observers. Although it is not thought that the order of showing the versions has any appreciable effect on the colour namings, this procedure should reduce the influence of any factors which depend on the order of showing.

The results of the naming of sixteen colours are given in Table 4. The range of colour names used by the women is greater than that used by the men and it will be observed that the corresponding percentages in either the "identical" class or the "identical and similar" class is usually lower for the women. Women are, in general, more interested in colour than men.

(a) Red separation positive

Fig. 6
Detergents

(b) Green separation positive

TABLE 4

Colour patch number	Colour of original	Approximate chromaticity co-ordinates of original illuminated by source C		Male observers		Female observers	
		x	y	Identical namings %	Identical and similar namings %	Identical namings %	Identical and similar namings %
1	Red	0·52	0·32	50	100	50	83
2	Blue	0·20	0·20	0	0	0	0
3	Red-orange	0·53	0·34	33	100	0	67
4	Orange-yellow	0·46	0·37	0	0	0	0
5	Red	0·53	0·34	50	100	0	67
6	Blue	0·21	0·24	33	50	0	33
7	Red	0·53	0·34	67	100	33	83
8	Yellow	0·44	0·49	0	0	0	0
9	Red	0·52	0·32	50	100	0	83
10	Yellow	0·44	0·49	0	0	0	0
11	Blue	0·14	0·18	0	0	0	0
12	Red	0·52	0·32	50	83	0	50
13	Blue	0·21	0·24	0	17	0	17
14	Red	0·53	0·34	83	100	0	83
15	Yellow	0·44	0·49	0	0	0	0
16	Green	0·28	0·44	0	0	0	0

Certain colours fail almost completely in the two-colour version (e.g. blue, yellow and green) and these colours are frequently used in display and packaging. If it were desired to transmit a colour television picture similar to Fig. 6, a two-colour process would leave a great deal to be desired in so far as colour accuracy was concerned. In reply to a question as to which of the two presentations was the more truthful, all twelve observers replied in favour of the three-colour version, including those who said that they were not very familiar with these particular packets: they could not imagine any manufacturer using the colours which are generated by the two-colour process. The only criticism made about the three-colour version was that the colours were a little too saturated. Most observers thought that the hues were correct.

3.5. Summary of Information from the Four Pictures

The mean percentages averaged over all colours for the "identical" and "identical and similar" classes of namings for the four slides are given in Table 5.

The most successful slides appear to be the portrait and the teapot slide, where two-thirds to three-quarters of the colours receive names which are similar, if

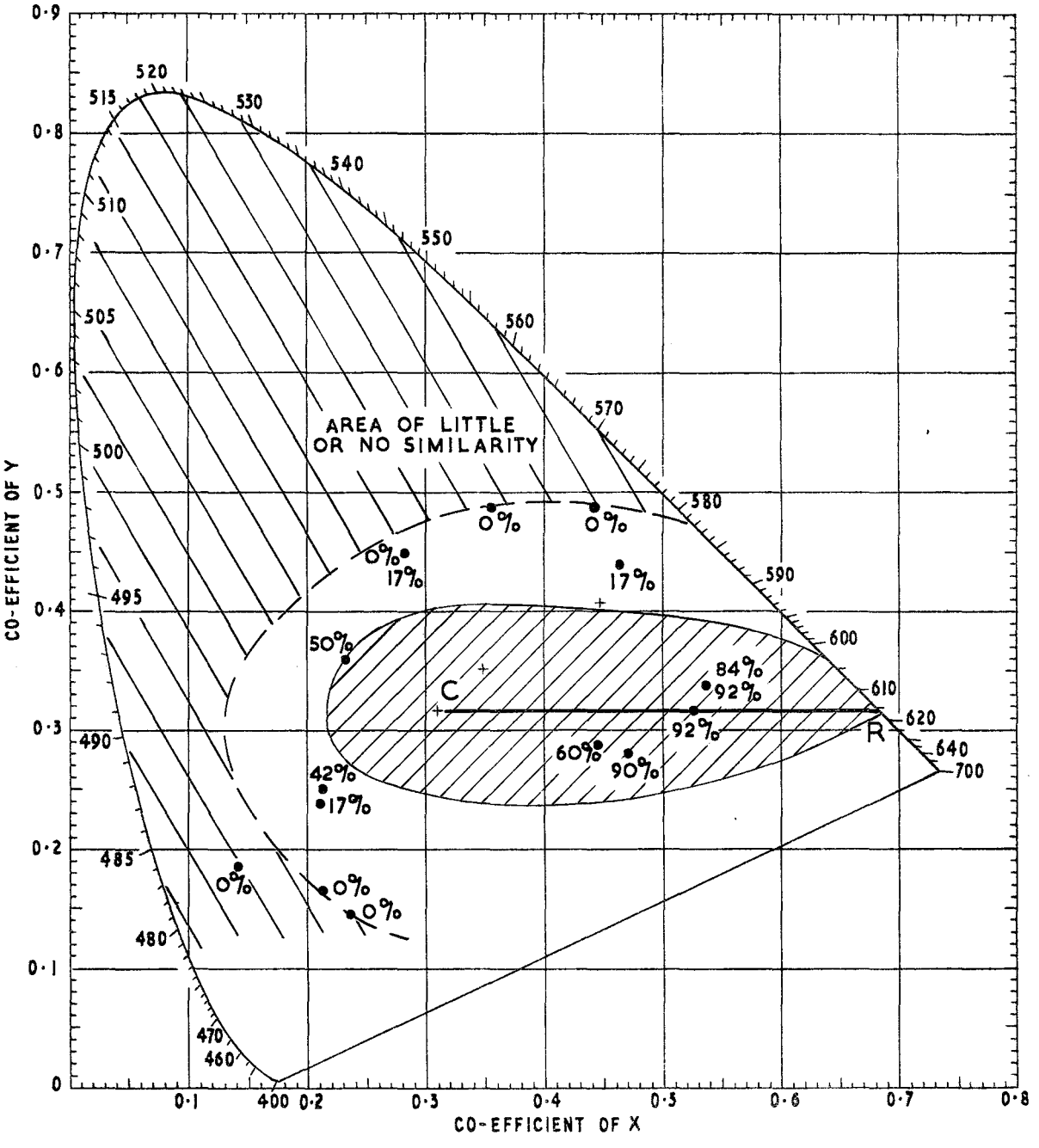
TABLE 5

Picture	Title	Mean identical naming %	Mean identical and similar naming %
1	Colour patches	23	40
2	Teapot slide	47	66
3	Portrait	42	75
4	Detergents (men)	26	47
	(women)	5	35

not identical, to the namings given to a three-colour reproduction of the same slide. In the case of slides 1 and 4, the two-colour reproduction has very glaring deficiencies.

An attempt has been made to give a rough estimate of the range of chromaticities over which the two-colour reproduction operates with an approximation to accuracy. The original colours in pictures 1 and 4 were compared with the chips in the Munsell Colour Atlas and the best available matches were found. The chromaticity co-ordinates of these colour chips illuminated in daylight (illuminant C) were read off from the data published by Kelly, Gibson, and Nickerson.[5] These figures are quoted in Tables 1 and 4. Fig. 7 is a chromaticity diagram showing the percentage of observers giving "identical and similar" colour names and, on the basis of these few points, an area has been drawn on the chromaticity diagram over which 50% or more of the observers use the "identical" or "similar" namings. A further contour is shown which marks an area over which virtually no accuracy in colour reproduction is achieved in large and medium sized areas of colour on the original article. The "objective" range of colours produced by a mixture of tricolour red and illuminant C is shown by the straight line CR (Fig. 7). The use of illuminant C in Fig. 7 is undesirable, but the available data[5] do not quote chromaticities in illuminant B. A subsidiary experiment showed little change in the range of colours produced when illuminant C is used for the green positive in place of illuminant B (although the change from illuminant A to illuminant B does seem to produce a marked improvement in the saturation). Hence, the areas shown in Fig. 7 are thought to be approximately correct, although the experimental data relate more nearly to illuminant B. In any case, far more colours would have to be investigated if any attempt were to be made to draw an accurate version of Fig. 7. Nevertheless, it is considered that this diagram represents to a first approximation the behaviour of a two-colour system according to Land in reproducing large and medium sized areas of colour.*

*In interpreting Fig. 7 it should be remembered that the C.I.E. diagram is not a uniform chromaticity chart and that the green area is much exaggerated. Note that the chromaticity co-ordinates of only one of the colour patches of Figs. 3 and 6 are well inside the area of little or no similarity.



THIS SHADED AREA IS THAT OVER WHICH NOT LESS THAN 50% OF THE OBSERVERS GIVE COLOUR NAMES WHICH ARE EITHER SIMILAR TO OR IDENTICAL WITH THE NAMES GIVEN TO A THREE-COLOUR REPRODUCTION

AREA OF LITTLE OR NO SIMILARITY IN REPRODUCTION

Fig. 7 - Approximate accuracy of colour rendering of two-colour process

In smaller areas it would appear that the range of colours which can be simulated is appreciably greater than the range shown in Fig. 7. Thus yellows, greens and blues have been named in the course of these experiments, although usually these colours are either desaturated or, alternatively, suffer from the admixture of neutral grey. On no occasion has a purple been reported and it seems that this colour is not simulated[6] by the particular version of two-colour reproduction which has been investigated in the present experiments.

4. COLOUR TELEVISION DEMONSTRATION

On Friday, 24th July 1959, a demonstration of a two-colour synthesis was given at Television Studios, Lime Grove. The picture-originating equipments were the Research Department film and slide scanner[7] and the Cintel 35 mm colour scanner. The R, G and B signals were fed both to a tricolour monitor[8] using an R.C.A. 21AXP22 tube and also to a trinoscope.[9] The latter display device had been modified by substituting a monochrome tube for the green cathode-ray tube and by disconnecting the blue tube. Thus, the trinoscope became identical in principle to the two-colour projection of white and red images as described in the previous sections.

A number of 3¼ in. (8·3 cm) square colour transparencies were shown both in the two-colour and three-colour versions, and it was observed that the effects produced were virtually identical with those observed in the optical projection experiments. The teapot slide (Section 3.2) was amongst those used and the same faults were observed (the most glaring of which was the inability of the two-colour version to reproduce the yellow Kodak box). One particular slide, showing a green B.B.C. field strength van in rural surroundings (grass and trees), completely failed to give any colour whatsoever in the two-colour version.

A 35 mm colour film was also shown and this frequently gave rise to scenes with almost no colour in the two-colour version, although a glance at the tricolour display showed a reasonable range of colours. The only obvious merit of the two-colour synthesis was its ability to produce acceptable flesh tones. In other respects it showed considerable shortcomings amounting either to the virtual absence of colour or, on other occasions, to a complete falsification of the colours.

5. DISCUSSION

The two-colour system (white plus red) frequently gives pleasantly coloured pictures which cover a greater range of colours than might be expected on the basis of objective colorimetry. Nevertheless, the range is so deficient (Fig. 7) that its use is not to be recommended for any system of colour television where a prime requirement is the ability to reproduce a wide range of colours (including greens, blues, yellows and purples) with a good approximation to the true colour. Standard three-colour systems at present in use in both colour photography and colour television succeed in doing this when sufficient care is taken to ensure correct colour balancing. The two-colour system is much less critical on colour balance and, in the case of flesh tones, it is very unlikely to generate unpleasant flesh tones even when the balance is disturbed. Three-colour reproduction has no such immunity and it is true that considerable care in instrumentation must be taken to obtain correct

colour rendering, particularly in the vicinity of the white point. However, three-colour processes are capable of reproducing a very wide range of colours: The two-colour system investigated in the present tests has shown marked deficiencies and the experimental results do not confirm the more extreme statements made by or on behalf of Dr. Land.[3]

6. ACKNOWLEDGEMENTS

The colour television demonstration described in Section 4 was given by the operations and maintenance staff of the Colour Telecine Section of the Lime Grove studios. This work was supervised by Designs Department.

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APPENDIX

DETAILED RESULTS OF NAMINGS FOR COLOUR PATCHES (SECTION 3.1)

Colour patch number	THREE-COLOUR						TWO-COLOUR						Number of namings in the stated category		
	Observer						Observer								
	1	2	3	4	5	6	1	2	3	4	5	6	Identical	Similar	Different
1	red	light brown	desaturated magenta	red	dark pink	red	red	light brown	orange-brown	light brown	orange	red	3	0	3
2	cyan	green-blue	cyan	cyan	light blue	cyan	blue-cyan	blue-grey	desaturated cyan	blue-grey	light blue	blue	1	2	3
3	magenta-brown	medium brown	brown	brown	brown	brown	deep magenta	medium brown	chocolate	dark red	brown	brown	3	2	1
4	orange-yellow	dark yellow	desaturated yellow	yellow	light orange	orange	orange	pinkish grey	pink	pink	pink	pink	0	1	5
5	green	dark green	green	green	green	green	green-cyan	dark blue-grey	dark desaturated cyan	grey	light grey	blue	0	1	5
6	green	dark green	green	green	green	green	green-cyan	dark blue-grey	dark desaturated cyan	grey	light grey	blue	0	1	5
7	red	pink	desaturated red	red	dark pink	light red	red	brick red	desaturated red	red	scarlet	red	3	1	2
8	blue	dark blue	violet	blue	navy blue	blue	black	very dark grey	very dark desaturated green	black	black	black	0	0	6
9	orange-yellow	dark yellow	desaturated yellow	yellow-orange	light orange	orange	orange-yellow	pinkish fawn	light pink	pink	pink	pink	1	0	5
10	magenta-brown	medium brown	brown	brown	brown	brown	deep magenta	medium brown	chocolate	brown	brown	brown	4	2	0
11	blue	very dark blue	violet	blue	navy blue	dark blue	black	very dark grey	very dark desaturated green	black	black	black	0	0	6
12	magenta-brown	medium brown	brown	brown	brown	brown	deep magenta	red/brown	chocolate	brown	brown	brown	3	3	0
13	light green	light green	light yellow-green	yellow-green	light green	light green	grey	light blue-grey	light grey	light grey	light blue	light grey	0	0	6